.

4th Concept answers to MDI Questions

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1. What factors determine the strength and shape of the magnetic field? Give a map of the field, at least on axis, covering the region up to ±20m from the IP. What flexibility do you have to vary the features of this field map?

   The magnetic field of the 4th concept[4] is established by two solenoids both symmetric with the central beam axis. The inner solenoid determines the tracking field, and the outer solenoid returns the flux in the annulus between the solenoids. The outer solenoid has about 1/3 the ampere-turns of the inner solenoid. This field is shown in Fig. 1 and is supported by the two solenoids and end-coils shown in Fig. 2, including the compensation solenoid around the beam axis.

   Field homogeneity in the central tracking region is established with additional turns in the coil added at the ends of the inner solenoid. These additional turn can be feed with a separate power supply as well. This axially symmetric field is easily calculated with ANSYS, and the conductors are based on the parameters and constraints of the CMS coil.

   The field strength can be changed over a moderate range, say a factor of two in either direction. In principle, we can scale the fields to whatever strength we like, since there is no iron with saturation. We are not strongly sensitive to the field strength, other than the inverse dependence of momentum resolution on B.

   We can easily vary features of this symmetric solenoidal field by separately varying the currents in the two solenoids and the end-coils. This will not affect the shape of the tracking field, but will affect the shape of the fringe field, and in particular the field along and near the z-axis. An illustration of the axial B_z field on the $z = 0$ axis, and the radial B_r field along $r = 30$ cm, are shown in Fig. 3

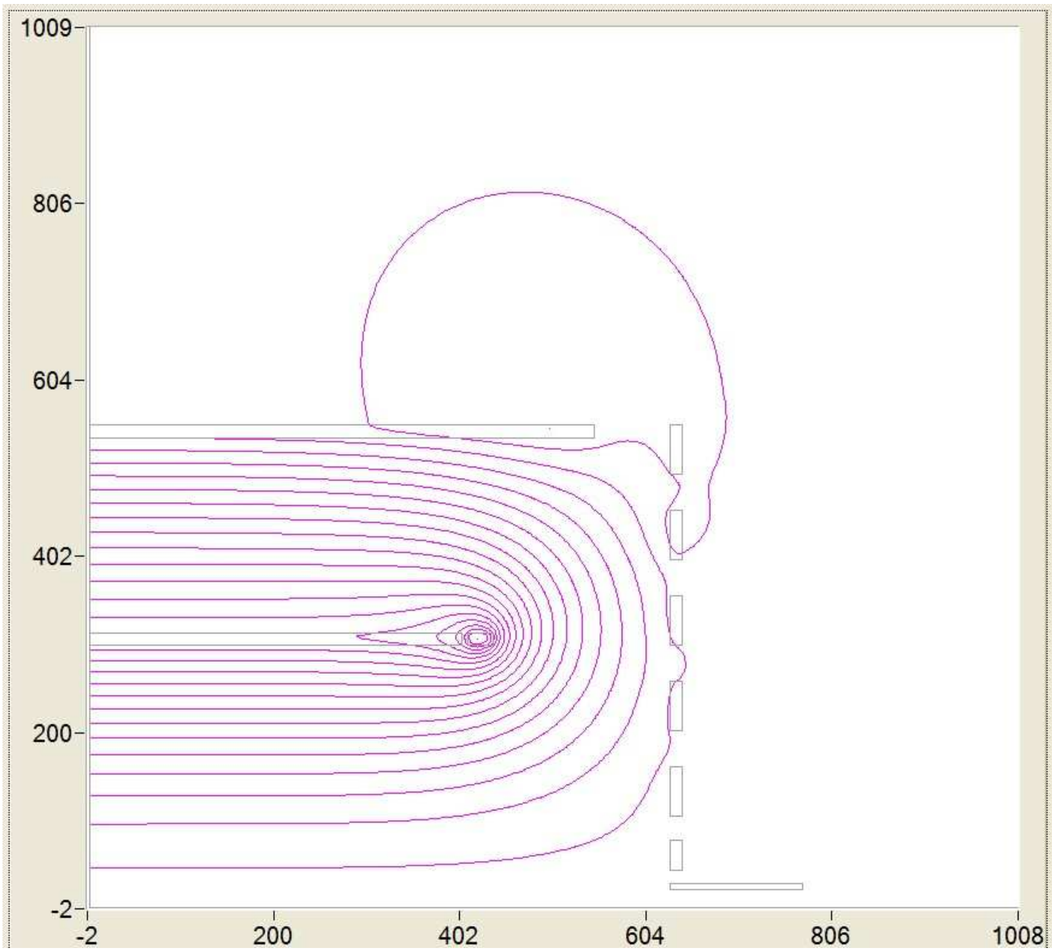

Figure 1: Magnetic field of the 4th Concept. The outer solenoid returns the flux from the inner solenoid, and the "wall of coils" at $z \approx 6.4$m confines the field to a cylinder by generating a strong radially outward field on the inside and a radially inward field on the outside that partly cancels the fringe field of the two solenoids. Some current is added at the end of the inner solenoid to increase the uniformity in the tracking region. The resulting field is uniform over large volumes inside the inner solenoid and in between the solenoids, and allows momentum bending of muons down to $\theta \approx 0.05$rad, negligible fringe field near the machine beam line, a B_z on the axis that becomes negligible at $z \approx 7$m, and almost complete control of the fields on and near the beam. The solenoid at $z \approx 7$m and $r \approx 0.2$m is not energized, and is intended for compensation of the beam twist.

2. Provide a geometry description of the detector components within 10m in z of the IP and within a radial distance of 50 cm from the beamline.

   There is a pixel vertex detector inside $r < 10$cm and $z < 50$cm; the TPC will come in to $r = 10$cm and extend to $z = 1.7$m including the readout end planes; the calorimeter can come as close to the beam as the fibers and the collider itself can tolerate; and, the

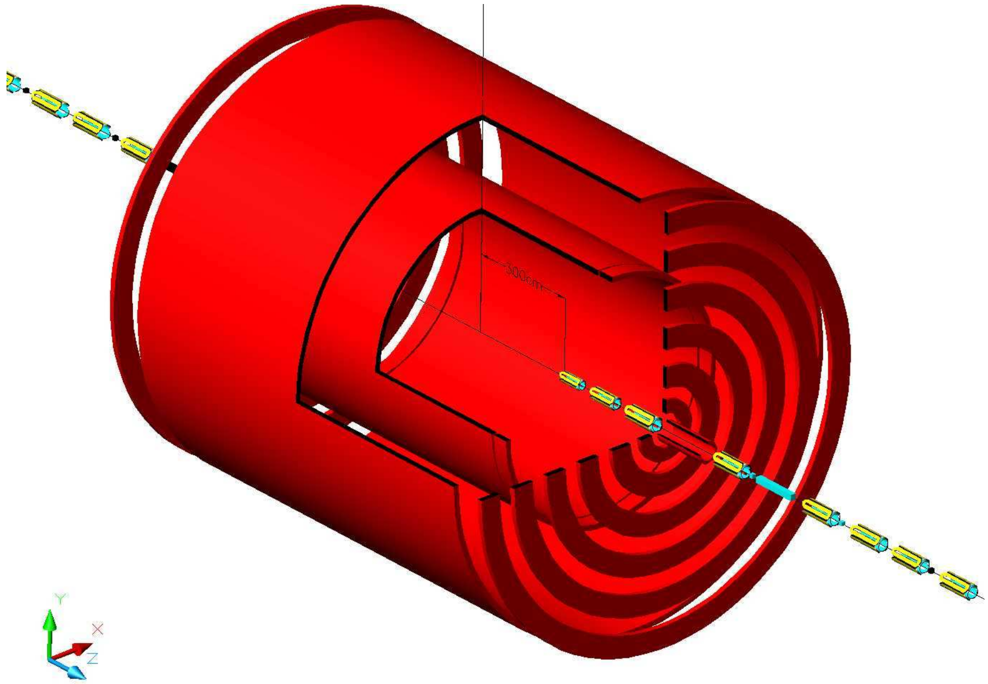

Figure 2: A cut-away view of the dual solenoids, the end coils that terminate the fringe field and also provide a strong radial field for azimuthal muon bending, the compensation solenoid, and beam line elements.

iron-free coils of the muon system will interfere with the beam stay-clears primarily due to the 70-cm width of the cold enclosure (CMS constraint) that we now assume in our calculations, but the muon end-coils have modest currents and can be, for example, LN_2 chilled Al conductors.

The most important point about the 4th Concept configuration is that the detectors at large z are modular, light, and easily reconfigurable. For example, the fiber calorimeter units are 4×4 cm^2 at their front face, and (in some simplified engineering sense) detachable modules. Thus, we can make the inner radius of the calorimeter whatever we want it to be, and this choice will be driven by the machine first, and detector acceptance second.

Likewise, the iron-free coils that establish the muon bending field [3] are light-weight (compared to an unmovable iron mass) and can be configured to make the field near the beamline almost whatever we want it to be, again, driven by the machine first, and detector acceptance second.

All elements of the FF optics, including final lenses, can be made iron-free. Low-Z materials can be used for the structural elements of the detector. Superconducting coils with a pure Al matrix can

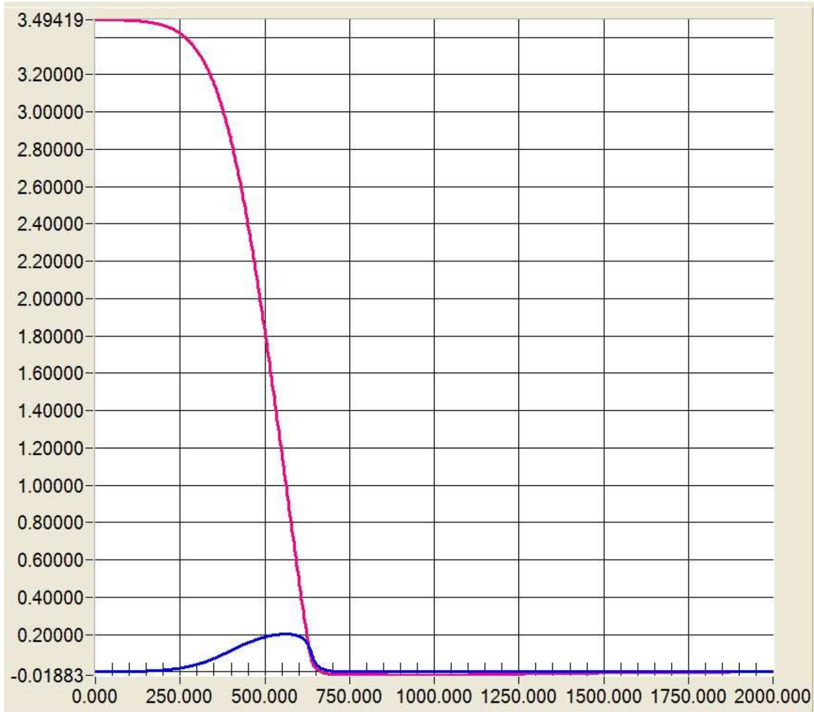

Figure 3: The axial B_z and radial B_r fields plotted together.

be considered for these purposes, such as the coil windings in the CMS coil. Stainless steel with low magnetic permeability can be used where it is necessary.

3. Would you mind if the baseline bunch-spacing goes to 150ns instead of 300 ns; with 1/2 the standard luminosity per crossing and twice as many bunches?

   No. The main detector subsystem is an optical calorimeter with very fast signal acquisition and readout. The TPC will be the limiting system in this instance with its e^- drift velocity under 10 cm/μs.

4. For each of your critical sub-detectors, what is the upper limit you can tolerate on the background hit rate per unit area per unit time (or per bunch)? Which kind of background is worst for each of these sub-detectors (SR, pairs, neutrons, muons, hadrons)?

   Starting from the inside:

   (a) the pixel vertex detector will suffer low occupancy by virtue of its huge number of (to be zero-suppressed) channels. Worst backgrounds are SR and pairs.

(b) the TPC with a 1-atmos. gas volume is most vulnerable to ionizing backgrounds, and therefore the worst backgrounds are SR and pairs. For a drift velocity of 10 cm/μs, an upper limit is about 100 particles per bunch crossing, easily handled by a 3-dim TPC. Clearly, the inner radii will see more beam-associated backgrounds.

(c) the fiber calorimeter is fast, all the light being emptied from the detector well before the next bunch crossing, and as a calorimeter, it is very robust with respect to backgrounds. The spatial segmentation will allow at least stray energetic particles to be identified. We will also be deliberately sensitive to the MeV neutrons created in nuclear break-up during hadronic shower development, so stray MeV neutrons are the worst background for hadronic shower energy measurement. We think a background rate of 100 neutrons per bunch crossing will be tolerable, assuming that the residency time of neutrons in the calorimeter mass is one bunch crossing time ($\sim$ 300 ns) and that a jet energy measurement will require interrogation of many nearby channels, effectively resulting in the whole calorimeter being a potential background source. This is a very pessimistic estimate.

(d) the muon system sits behind 10 λ_I of calorimeter, and in addition we may place a non-magnetic filter beyond the gaseous tracking volume momentum measurement annulus. The worst backgrounds will be from hadronic punch-through, but the physics rate will be larger than the tolerable background rate, and the muon system in the 4th Concept has extraordinary pion rejection capability.

5. Can the detector tolerate the background conditions for the ILC parameter sets described in the Feb. 28, 2005 document at www-project.slac.stanford.-edu/ilc/acceldev/beamparameters.html? Please answer for both 2-mrad and 20-mrad crossing angle geometries. If the high luminosity parameter set poses difficulties, can the detector design be modified so that the gain in luminosity offsets the reduction in detector precision?

   This is an issue for all detectors; for example, three concepts have TPCs, three concepts depend on PFA, all concepts have vertex detectors, etc. Like the answer to Question 2, we believe that the 4th concept configuration is relatively flexible near the beamline and, although the pixel and TPC detectors are fixed geometrically, the calorimeter can be reconfigured near the beam line since it is so modular.

6. What is your preferred L^*? Can you work with 3.5m$< L^* <$ 4.5m? Please explain your answer.

For zero crossing angle, which is preferable, shorter L^* (the distance between IP and the first lens) is better. Shorter L* makes problems with chromaticity compensation easier to handle. The design of the FF lenses with SC coils allows for compact installation closer to the IP.

7. What are your preferred values for the microvertex inner radius and length? If predicted backgrounds were to become lower, would you consider a lower radius, or a longer inner layer? If predicted backgrounds became higher, what would be lost by going to a larger radius, shorter length?

   The inner radius is determined by the halo cut at the entrance to the detector. With an appropriately designed collimator, this radius can be 1-2 cm. Therefore, the inner radius at the IP is presently 1.5 cm, determined by the 3.5T field and physics efficiencies for tagging b, c quarks and the τ. The axial extent of the innermost pixel vertex cylinder is about 20 cms. This barrel is terminated with a disk pixel whose inner radius is not yet determined, but will likely depend completely on the backgrounds that are the point of this question. This prompts us to be cognizant of the capability to remove the inner annuli from the disk detectors if these backgrounds are too high or if the pixels can be damaged by the beam.

8. Are you happy that only 20mr and 2mr crossing angles are being studied seriously at the moment? Are you willing to treat them equally as possibilities for your detector concept.

   Any angle can be tolerated. The preferable configuration is zero crossing angle (head-on collisions), however, even for 150 ns spacing. A larger angle makes the forward $2\gamma \to e^+e^-$ tagging and rejection much more difficult. Also, there are more holes in the forward calorimeter and the luminosity calorimeter, with consequent smaller effective fiducial volumes for physics acceptance. We do not know, but can guess, that backscatter from these elements will be worse for the detector for these larger crossing angles.

9. Is a 2mr crossing angle sufficiently small that it does not significantly degrade you ability to do physics analysis, when compared with head-on collisions?

   Yes, we think so, and it can be tolerated.

10. What minimum veto and/or electron-tagging angle do you expect to use for high energy electrons? How would that choice be affected by the crossing angle? How does the efficiency vary with polar angle in each case?

    Zero crossing angle allows the minimum detector angle, directly. It is clear that this angle could be $\sim$ 3cm/300cm in the extreme case. We think we can bring the fiber calorimeter effective edge down to within 8 cms of the beam, and therefore about a tagging angle of 20 mrad. The forward detectors being designed in the MDI group will fill this region, although we can go closer to the beam to shadow the forward calorimeter. Clearly, the necessary needs of the MDI detectors at small angles must come first, and at least for the calorimeter we can come as close as possible. In the end, only the fibers will fry.

11. What do you anticipate the difference will be in the background rates at your detector for 20mr and for 2 mr crossing angle? Give you estimated rates in each case.

    The background rates are defined by collimation at the entrance, the disruption parameter at the IP, and the overall design of the FF optics. Again, zero crossing angles result in less background. If the 2 mrad crossing angle is chosen, then the optics design becomes a more difficult task, since one now needs to direct the beams in separate channels.

12. What is your preliminary evaluation of the impact of local solenoid compensation (see LCC note 143) inside the detector volume, as needed with 20mr crossing angle, on the performance of tracking detectors (silicon, and/or TPC, etc.)

    Solenoid compensation can be made with a compact solenoid. Its field is local and does not propagate to the pixel system and does not affect the performance of tracking detectors. If we characterize the B_r field as a function of z in LLC 143 as a small, 2% distortion of the local field, then this is easily handled in the reconstruction software for the pixel vertex and the long-drift TPC. Therefore, we think it is not a concern.

    Our compensation solenoid is depicted in Fig. 2 at about $z \approx 7$ meters, and this solenoid has a B_z field shown in Fig. 4 of about $B_z \approx -11$T to compensate for ribbon rotation of the central tracking field.

    Details of the B field inside the compensation solenoid and in the vicinity of the end-coils are shown in Fig. 5. These fields are approximately optimized for this concept, although it is clear that not only can we further optimize, but we can also reshape the fields to almost whatever we want them to be on and near the beam line.

13. Similarly, what is you preliminary evaluation of the impact of compensation by anti-solenoids (LCC note 142) mounted close to the first quadrupole?

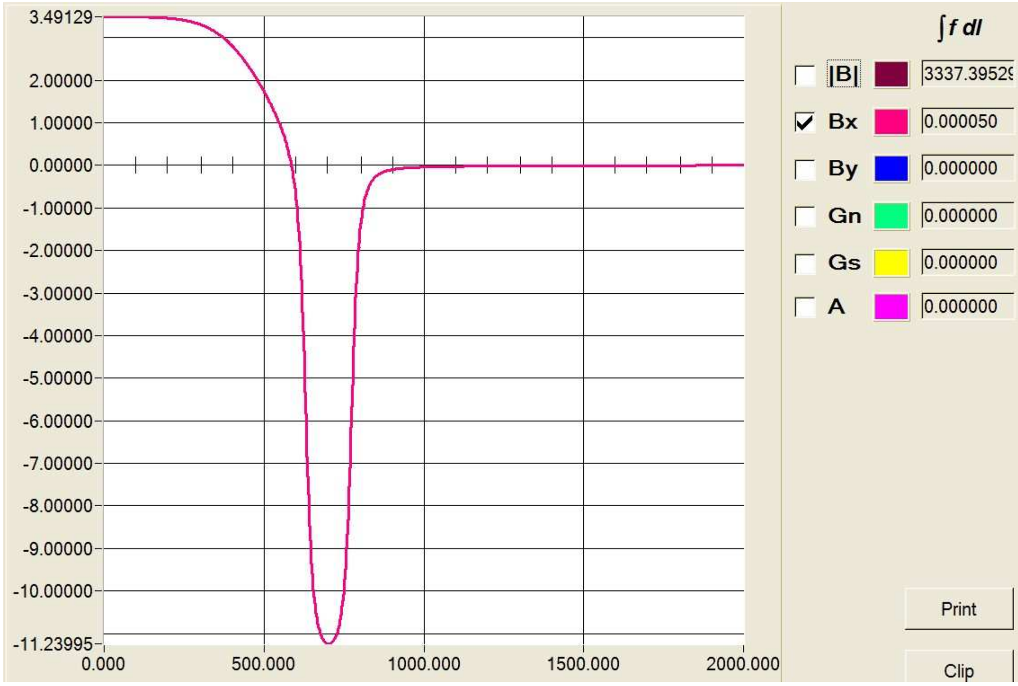

Figure 4: The longitudinal field B_z along the z-axis from the center of the tracking region ($B_z \approx +3.5$T), through the compensation solenoid ($B_z \approx -11$T), and out to large z ($B_z \approx 0$).

This requires a full simulation of the fields and masks. As stated in Question 1, we have a dual-solenoid without iron ends, and in addition we will have a "wall of coils" to cover the region beyond $cos\theta > 0.85$ in the muon system. It is not clear how close this system can and should come to $cos\theta = 1$. The spray of low energy electrons will be so complicated, that it must be carefully simulated.

14. Do you anticipate a need for both upstream and downstream polarimetery and spectrometry? Precision, and effect of 2mr and 20mr?

Spectrometry does not depend on crossing angle as the beam is running straight, and the crossing angle does not matter. Spectrometry before and after is desirable and could be arranged with the help of evacuation optics for head on-collision in a more natural way. In the end, this is common to all groups and will be a decision for everyone, and involve important judgments by the GDE.

15. Is $e^+e^- \to Z$ calibration needed? How frequently and how much? What solenoid field would be used for $e^+e^- \to Z$ running? Also, polarimetry and beam energy measurements needed for $e^+e^- \to Z$ running?

Substantial data are needed to confirm the calibration of the calorimeter, and at the same time, spatially calibrate the tracking sys-

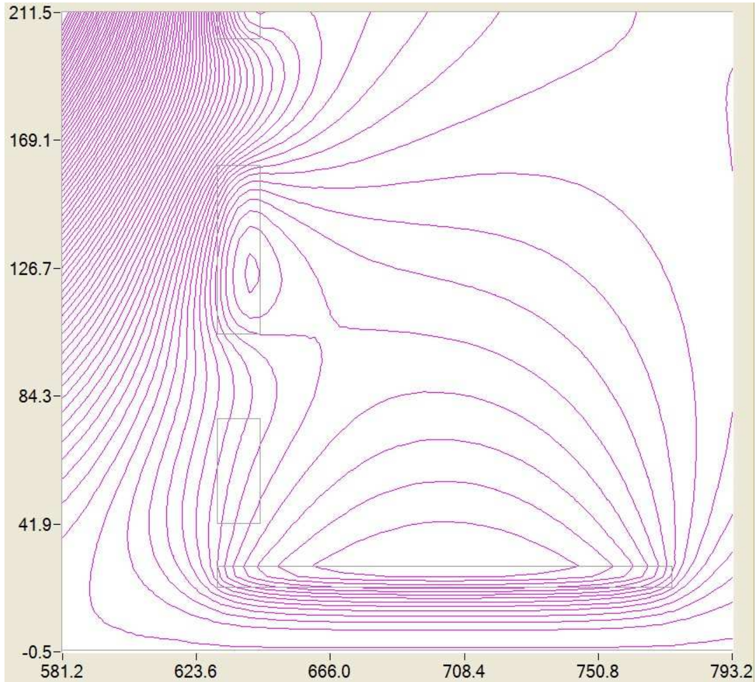

Figure 5: The magnetic field lines of the compensation solenoid in the vicinity of the first three coils of the "wall of coils"

tems, pixel vertex and TPC. About 10^8 electrons will be sufficient to completely calibrate the dual-readout calorimeter [1]. We have found in the beam test that the calibration is easy, stable, and above all, the hadronic energy response is linear (from 20 to 300 GeV beam energies) in this dual-readout calorimeter *that was calibrated only once on 40 GeV electrons.* Therefore, we are completely confident that the calorimeter calibration can easily be established with Z running, and we can use $Z \to ee$, $Z \to \mu\mu$, and $Z \to jj$. During running at physics energies, we are again completely confident that the linearity of the hadronic response and the electromagnetic response will allow precision checks and continual calibration using the W and Z masses.

16. Would you like the e^-e^- option in the baseline?

    The e^-e^- option will be defined by the physics interests of the community, not by the detector design. This is a big question that the GDE and the community as a whole must agree upon.

17. What will be your detector assembly procedure?

    In the 4th concept design, the detector elements are easily accessible due to the iron-free magnetic field configuration. We are designing a rather modular detector, at least as far as the fiber calorimeter and the muon tracking annulus are concerned. The muon bending fields are established by supeconducting coils inside cryostats, which are not so modular, but are at least reconfigurable. All of this allows quick (re)installation.

18. What is the size of the detector hall?

    The absence of a heavy iron yoke and the necessity to assemble and disassemble it allows the cave of the 4th concept to be more compact. Final dimensions will emerge after a final design is made but definitely the size will be less that a detector with an iron-yoke. Presently, the outer physical perimeter of 4th will be about 6.5m in radius and about 12m axially. These dimensions are the size of the outer solenoid of the muon dual-solenoid. This is modest, at least compared to existing LHC detectors.

References

[1] "Hadron and Jet Detection with a Dual-Readout Calorimeter", N. Akchurin, *et al.*, *Nucl. Instrum. and Methods* **A537** (2005) 537-561.

[2] Alexander Mikhailichenko is MDI Contact for the 4th Concept detector.

[3] "Dual-solenoid magnetic field for the 4th Concept", J. Hauptman, R. Wands, S. Popescu, A. Penzo, N. Akchurin, F. Grancagnolo, Note-Muon-2006-1, 2 January 2006. This initial and crude field has been completely superceded by the fields calculated by A. Mikailichenko and described in the 4th Detector Outline Document (DOD).

[4] The 4th Concept Detector Outline Document is available at http://physics.uoregon.edu/~lc/wwstudy/concepts.